REMARKS

In the Office Action dated December 31, 2003, an incorrect dependency in claim 31 was noted by the Examiner, which has now been corrected.

Claims 1, 2, 6, 11, 12, 22, 23 and 27-29 were rejected under 35 U.S.C. §102(b) as being anticipated by Glace. Claims 7 and 8 were rejected under 35 U.S.C. §103(a) as being unpatentable over Glace. Claims 13, 14, 30 and 31 were rejected under 35 U.S.C. §103(a) as being unpatentable over Glace in view of Desai.

Claims 15-21 and 32-35 were allowed, and claims 3-5, 8, 10 and 24-26 were stated to be allowable if rewritten in independent form.

The above rejections are respectfully traversed for the reasons set forth below, and therefore the claims that were stated to be allowable if rewritten in independent form had been retained in dependent form at this time.

The following arguments in support of patentability apply to each of independent claims 1 and 22. In general, it is Applicants' position that the Glace reference does not obtain or employ unipolar signals at all, as required in claims 1 and 22, and further it is the Applicants' position that the signals that are obtained in the Glace reference (which are bipolar signals) are not analyzed for the purpose of indicating a cardiac rhythm abnormality, as also required in claims 1 and 22.

With regard to the lack of a teachings in the Glace reference to obtain or use unipolar signals, Applicants submit the following comments.

Each of independent claims 1 and 22 requires that unipolar electrical signals be obtained from cardiac tissue via the plurality of electrodes disposed at the tip of the cardiac lead. These unipolar signals are then analyzed with regard to their time

relationships to obtain an analysis result, which is then used to detect the presence of a cardiac rhythm abnormality.

In substantiating the rejection of claims 1 and 22 as being anticipated by the Glace reference, the Examiner stated the electrical signals obtained by the electrodes in the device disclosed in the Glace reference as considered to be unipolar in nature "by virtue of the fact that each electrode produces an independent electrical signal (see Fig. 5 wherein electrode one produces signal 23, electrode two produces signal 24, and so on)." The Examiner further stated that "if electrodes one and two were combined in a bipolar arrangement, each pair would result in one signal."

As the Examiner is aware, the terms "unipolar" and "bipolar" are well known terms to those of ordinary skill in the field of cardiac stimulation, and they have unambiguous, well known meanings to such persons of ordinary skill. The individual electrodes disclosed in the present application are unquestionably unipolar, and the signals obtained therefrom thus are unipolar signals. Such signals are not the same as signals obtained from bipolar electrode arrangements. Applicants submit that the Glace reference is unquestionably an example of a system using a bipolar electrode arrangement, and therefore the signals obtained and analyzed in the Glace system are unquestionably bipolar signals. Applicants recognize that the Examiner is required to give terms in a patent claim their broadest reasonable meaning, however, the Examiner is not at liberty to disregard well-known and well-understood meanings of terms in the field to which the claimed subject matter pertains.

Attached hereto as Attachment "A" are pages from a pacing glossary, providing the basic definitions of "unipolar" and "bipolar" as those terms are

understood by those of ordinary skill in the art. The term "unipolar" is used in the present application consistent with the well-understood meaning that it has to those of ordinary skill in the field of cardiac stimulation and sensing. Also attached hereto as Attachments "B" and "C" are excerpts from cardiac pacing texts, explaining the well-understood differences between unipolar signals (i.e., signals obtained with a unipolar electrode arrangement) and bipolar signals (i.e., signals obtained with a bipolar electrode arrangement).

The fact that the Glace reference is concerned exclusively with bipolar sensing, and analysis of bipolar signals, is made clear at a number of locations in the Glace reference. Figures 1a and 1b of the Glace reference illustrate the "probes" that are used to obtain the signals in the Glace reference that are analyzed to determine cardiac rhythm abnormalities. Each of those probes clearly has two electrodes, numbered 1 and 2. Figure 1a shows an epicardial probe and Figure 1b shows an endocardial catheter. In all instances, the signals that are analyzed are obtained between or across the electrodes 1 and 2. Applicants therefore disagree with the Examiner's statement that Figure 5 shows a signal 23 that is produced by electrode 1 and a signal 24 that is produced by electrode 2. In the paragraph beginning at column 5, line 28 of the Glace reference, it is clear that the electrodes are always being considered in pairs, and thus it is clear, despite the somewhat imprecise language in the paragraph beginning at column 5, line 53, that the signals 23 and 24 and 26 and 27 shown in Figure 5 are obtained from electrode pairs, rather than from individual electrodes.

This is explicitly stated in the Glace reference at column 2, lines 10-11, wherein the probe is stated to be composed of at least one assembly of two sensors

(the sensors being the aforementioned sensors designated 1 and 2 in the Glace disclosure).

This is also made clear by the intentional arrangement of the electrodes in pairs shown in Figures 4a and 4b of the Glace reference.

This is also made clear by the type of analysis of the aforementioned signals that is undertaken in the Glace reference, wherein so-called azimuth angles are obtained, with the "azimuth" being the straight line proceeding through the two electrodes in each pair. If the signals to be analyzed did not originate with an electrode pair having such an axis, there would be no point to determining an azimuth angle. In the case of a true unipolar electrode, there is no such thing as an azimuth angle because the signal originates from one electrode at the lead tip.

Moreover, Figure 8 makes clear that even if the probes 1 and 2 are considered separately, each of those probes consists of two electrodes, which feed signals into respective amplifiers 34. Since both signals from electrodes proceed to the same amplifier 34, there is no way to separate those signals for subsequent analysis, as would be necessary if each of those signals were considered a unipolar signal. In other words, if the signals generated by the respective electrodes in the Glace reference were to be analyzed as unipolar signals, there would have to be a separate amplifier channel for each of those signals, contrary to what is shown in Figure 8 of the Glace reference.

Therefore, it is clear that the disclosure of the Glace reference is exclusively concerned with obtaining signals with a number of bipolar electrode arrangements, and it is essential to the intended operation of the Glace system that those signals be analyzed in a manner that is dependent on the bipolar electrode arrangement from

which the respective signals were obtained. Not only is the sensing in the Glace reference undertaken exclusively with bipolar electrode arrangements, the signal analysis proceeds based on the knowledge that the signals were obtained in that manner.

It is true that in an embodiment of the present invention one of the electrode dots can be used as a reference, but this does not mean that a voltage is measured across the reference electrode dot and another electrode dot. Use of one electrode dot as a reference means that the unipolar signal obtained with the reference electrode dot is subtracted from the respective unipolar signals obtained from other electrode dots. Forming a difference (subtracting) between two unipolar signals obtained from two electrodes, respectively, does not result in a signal that is the same as a bipolar signal across those two electrodes.

Of course, each of the amplifiers 34 in the Glace reference has one output, however, the signal at each of those outputs, for the reasons discussed above, is not considered by those of ordinary skill in this field as being a "unipolar" signal.

New claims 55 and 56 have been added that state that the number of unipolar signals that are obtained is equal to the number of electrodes. As noted above, even if the Glace reference (contrary to Applicants' assertions above) is somehow "interpreted" as disclosing unipolar electrodes, it is clear that the signals that are obtained and analyzed are *not* equal in number to the number of electrodes. In the Glace reference, the number of signals is one-half the number of electrodes.

The Glace reference, therefore, does not anticipate either of claims 1 or 22, or any of the claims respectively depending from those independent claims.

Moreover, although a rejection of those claims based on the Glace reference under 35 U.S.C. §103(a) was not made, it should be clear from the above discussion that modifying the Glace reference to employ unipolar electrodes to obtain unipolar signals would destroy the intended operation of the Glace reference, since the purpose for using bipolar electrodes to obtain bipolar signals is crucial for the intended purpose of the Glace reference.

This leads to Applicants further arguments in support of patentability, namely that the obtained signals (regardless of whether they are characterized as "unipolar" or "bipolar") in the Glace reference are *not* analyzed to identify a cardiac rhythm abnormality. The intended purpose of the system disclosed in the Glace reference is to analyze the phase shifts represented by the aforementioned sensor pairs by moving the probe relative to the myocardium to locate a position at which all of those phase shifts are zero. This is then taken to be the source of an existing cardiac rhythm abnormality. Therefore, in the Glace reference it is not a cardiac rhythm abnormality that is being identified or detected, it is a physical location. In the Glace reference, it is essential that a cardiac rhythm abnormality *already be occurring* when the aforementioned signals and phase shifts are obtained. If no cardiac abnormality were occurring, the location at which the phase shifts are zero could not be identified. The purpose of identifying this zero point in the Glace reference is to designate a location for cardiac ablation or excising.

This is a further reason why the Glace reference does not anticipate either of claims 1 or 22, or any of the claims respectively depending from those independent claims.

Claims 7 and 9 add further steps to the novel and non-obvious method of independent claim 1, and therefore would not have been obvious to a person of ordinary skill in the art under the provisions of 35 U.S.C. §103(a) based on the teachings of the Glace reference, for the same reasons discussed above in connection with claim 1.

Similarly, even if the Glace reference were modified in accordance with the teachings of Desai, the subject matter of claims 13, 14, 30 and 31 still would not result, for the reasons discussed above. Claims 13, 14, 30 and 31, therefore would not have been obvious to a person of ordinary skill in the art under the provisions of 35 U.S.C. §103(a) based on the teachings Glace and Desai.

All claims of the application are therefore submitted to be in condition for allowance, and early reconsideration of the application is respectfully requested.

Submitted by,

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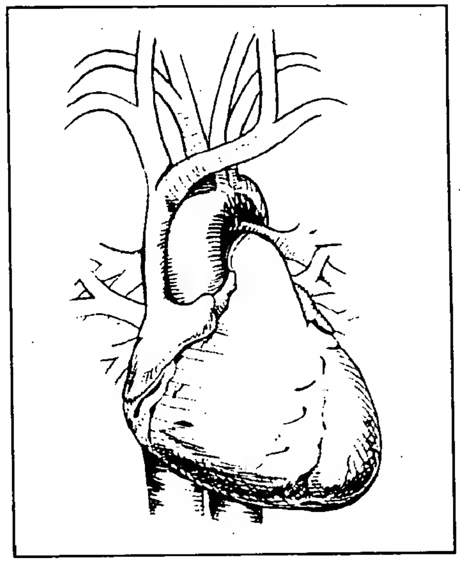
CARDIAC RHYTHM MANAGEMENT

GLOSSARY



ST. JUDE MEDICAL

ATTACHMENT "A"

Bipolar. Having two poles. In pacing and ICDs, a bipolar *lead* contains two *distal electrodes*. Bipolar pulse generators are devices that can accommodate such a lead. See also *unipolar*.

Bipolar Lead. A pacing lead fitted with two *electrodes* at the *distal* portion of the lead. When administering a pulse or sensing electrical activity, the pulse generator equipped with a bipolar lead uses one *electrode* as the *anode* and one as the *cathode*, limiting its pacing and sensing to the tip of the lead. Bipolar leads typically result in relatively small *spikes* on the ECG. See also *unipolar lead*.

Bipolar Pulse Generator. A pulse generator that can pace and sense with the *distal* two electrodes of a *bipolar lead*.

Bit. An acronym for "binary digit"; the smallest unit of information that can be recognized by a computer. It can have only two possible values: 0 or 1. See also *binary code*.

Biventricular Pacing. A pacing system that stimulates both ventricles in an effort to synchronize contractions and improve cardiac output.

Blanking Period. A *preset* or programmable interval (in ms) during which the *sense amplifier* of the pulse generator is temporarily *disabled*. The atrial or ventricular blanking period can begin with delivery of an *output* pulse or when the device senses intrinsic *conduction*. In dual-chamber pulse generators, the blanking period is intended to prevent inappropriate detection of signals from the opposite chamber (*crosstalk*). The first portion of the *PVARP* is an *absolute refractory period* known as the *post-ventricular atrial blanking period (PVAB)*.

Block Response. An *upper rate behavior* in dual-chamber *tracking* modes in which the ventricular rate is one-half to one-third the native atrial rate. This occurs when the *intrinsic* atrial rate exceeds the programmed *maximum tracking rate* to a sufficient degree that only every "nth" *P-wave* is sensed and tracked and when the intrinsic atrial *cycle length* is shorter than the *TARP*.

BPEG. See *British Pacing and Electrophysiology Group*.

BPM. Abbreviation for beats per minute. Usually refers to an intrinsic *heart rate*, while pulses per minute (ppm) usually refers to the paced rate. See also *ppm* or *min^{-1}*.

Bradycardia. Slow *heart rate*, usually defined as less than 60 beats per minute or any rate that is too slow to be physiologically appropriate for the patient's age, condition, and activity level.

Bradycardia-Tachycardia Syndrome. A syndrome characterized by fast and slow heart rates, affecting the electrical *conduction* system of the heart, mainly the sinus node and the atrium. Atrial tachycardias (most often atrial *fibrillation*) are associated with *sinus bradycardia* and can cause sinus arrest when they terminate. Bradycardia-tachycardia syndrome is a subset of *sick sinus syndrome*, and is also called tachycardia-bradycardia syndrome and brady-tachy syndrome.

British Pacing and Electrophy-iology Group. A subdivision of th British Cardiac Society which work closely with *NASPE*.

Bundle Branch Block (BBB). An intraventricular *conduction* disorder which the conduction of electrical impulses through the right or *left bundle branch* is partially or completely interrupted. Bundle branch block causes one of the ventricles t contract before the other.

Bundle Branch Reentrant Tachy-cardia. A form of *ventricular tachycardia* characterized by a successior of bundle branch reentrant complexes. *His bundle* deflections can b recorded preceding each *ventricular depolarization*. About one-third of th sustained *manomorphic ventricular tachycardias* occurring in patients wi dilated cardiomyopathy are reported to be of this type, which may be cure by *ablation* of one of the key *conduction* pathways.

Bundle of His. See *His bundle*.

Bundle of Kent. See *Kent bundle*.

Burst Cycle Length (BCL). The length of time (interval) between *ant tachycardia pacing*, *NIPS*, or *fibber* pulses.

ʏ. An *arrhythmia* charac-
ʏ repeating patterns of three
ith one *premature ventricular*
on following two normal

ED. (1) A pulse generator's
ɜ to sensing in which a sensed
ggers an *output* pulse. It is the
: of inhibited response, in
sensed event inhibits the
ulse. Examples of triggered
nodes are *AAT* and *VVT*. *DDD*
ɔ are also triggered modes
n atrial event triggers a ven-
utput after a *preset* delay or
r *PV interval*. In the *DDT*
ı sensed event will also trigger
ut in the ventricle after the AV
elay. (2) Events initiated by the
ɔr clinician, sometimes using a
. For example, the patient-
d event records in Trilogy®
ıkers, or patient-triggered anti-
rdia therapies in ICDs.

ER'S SYNDROME. The con-
ɔr unconscious rotation of an
ed pulse generator by a
Constant manipulation of the
through the overlying tissue
coiling of the lead(s) and may
ı lead fracture and/or gradual
ing and eventual *dislodgment*
ead.

U

UNDERDRIVE PACING. Pacing at a rate slower than a *tachycardia*, which can sometimes interrupt and terminate a reentrant *arrhythmia*.

UNDERLYING RHYTHM. The basic *intrinsic* rhythm on which the paced rate or certain arrhythmias may be superimposed, e.g. sinus arrest, sinoatrial (SA) *exit block*, atrial *fibrillation* or *AV block*.

UNDERSENSING. The failure of the pulse generator to sense P- or R-waves, causing delivery of inappropriately timed, *asynchronous* or competitive *output* pulses. Undersensing can sometimes be corrected by programming the device to a more sensitive setting, i.e., decreasing the mV value. In ICDs, undersensing may result in asynchronous pacing with subsequent double-counting of intrinsic and pacing pulses, which may cause *tachycardia* therapy to be delivered. Conversely, undersensing may result in failure to detect a tachycardia rhythm and thereby prevent delivery of therapy. See also *oversensing*.

UNIPOLAR. Having one pole. May refer to a lead with a single *electrode* or a pulse generator that can accommodate such a lead. Unipolar is actually a misnomer, in that the circuit must have two poles (the pulse generator *case* serves as the other pole) even if the lead itself does not. See also *bipolar*.

UNIPOLAR LEAD. A lead with a single electrical pole at the *distal* tip of the lead (negative pole). The *anode* (positive pole) is the pulse generator *case*. The *cathode* is the *electrode* through which the stimulating pulse is delivered. See also *bipolar lead*.

UNIPOLAR PULSE GENERATOR. A pulse generator that can accommodate a *unipolar lead* and operate in a *unipolar* pacing and sensing *configuration*.

UPPER LIMIT OF VULNERABILITY (ULV). The phenomenon in which there is a maximum *energy* level above which shocks delivered to the ventricle during *repolarization* will no longer induce *ventricular fibrillation*. This upper limit of vulnerability correlates closely with the *defibrillation threshold*. These observations, among others, led to the ULV hypothesis of *defibrillation*, which states that shocks that fail to defibrillate the heart may actually stop and then reinitiate *fibrillation*.

UPPER RATE BEHAVIOR. The behavior of the pulse generator when the sensed atrial rate exceeds the programmed maximum tracking or maximum sensor rate. See also *maximum tracking rate, maximum sensor rate, pseudo-Wenckebach*.

UPPER RATE LIMIT INTERVAL. See *maximum tracking rate*.

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Practical Cardiac Diagnosis

Cardiac Pacing

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ATTACHMENT "B"

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than prolonging battery longevity, polarization impedance is detrimental. Polarization impedance is directly related to the duration of the pulse and can be minimized by the use of relatively short pulse widths. Polarization is inversely related to the surface area of the electrode. In order to minimize the effect of polarization (Z_p) but maximize electrode resistance (Z_e), the surface area of the electrode can be made large but the radius small by the use of a porous coating on the electrode.[114–117] Electrodes constructed with activated carbon,[118–120] or coated with platinum black[121–124] or iridium oxide are effective in minimizing the wasteful effects of polarization.

The evolution of pacing impedance is usually characterized by a fall over the first one to two weeks following implantation[46,59,125] The chronic pacing impedance then rises to a stable value that is, on average, approximately 15 percent higher than at implant. Serial measurements of pacing impedance are extremely valuable for the assessment of lead integrity; low impedance measurements usually reflect a failure of conductor insulation, and high values often suggest conductor fracture or a loose set-screw at the proximal connector. It should be emphasized that the method of measurement greatly influences the impedance value. For example, if the pacing impedance is measured at the leading edge of the pulse, the value reflects Z_c and Z_e but not Z_p. In contrast, measurements near the midpoint of the pulse are a more accurate reflection of total pacing impedance. For clinical purposes, serial assessments of impedance should utilize a consistent method of measurement.

BIPOLAR VERSUS UNIPOLAR STIMULATION

The term "unipolar" pacing is technically a misnomer, as both bipolar and unipolar configurations require an anode and a cathode to complete the electrical circuit. Because both unipolar and bipolar pacing utilize an electrode in contact with the myocardium as the cathode, the difference in these configurations lies in the location of the anode. For unipolar pacing, the anode is the case of the pulse generator. The anode for bipolar stimulation is located on the pacing lead in the heart, either in contact with the endocardium or lying free within the cardiac chamber. The conductor impedance is slightly higher with bipolar pacing, as two conducting wires are required. However, the stimulation threshold is usually identical with either elec-

trode configuration. The clinically important differences relate to sensing, where the advantages of bipolar leads are substantial, and to the increased dimensions and reduced flexibility of bipolar leads.[126] Bipolar pacing is also devoid of the potential for pectoral muscle stimulation, which is sometimes encountered with unipolar stimulation. The increased size of the pacing stimulus (with unipolar pacing) on the surface electrocardiogram may occasionally be useful for the assessment of proper pacemaker function. With the introduction of artificial sensors for rate-adaptive cardiac pacing, bipolar leads offer a somewhat greater range of sensor options, especially for sensors measuring cyclic changes in impedance.

SENSING

Sensing of the cardiac electrogram is essential to the proper function of permanent pacemakers. In addition to responding to appropriate intrinsic atrial or ventricular electrograms, permanent pacing systems must be able to discriminate these signals from unwanted electrical interference: far-field cardiac events, diastolic potentials, skeletal muscle signals, and pacing stimuli. In this section, the basic determinants of electrogram sensing will be discussed.

Intracardiac electrograms

Intracardiac electrical signals are produced by the movement of electrical current through myocardium. An electrode that overlies a region of resting myocardium records from the outside of cardiac myocytes, which are positively charged with respect to the inside of the cell. Despite this, an electrode in one region of resting myocardium will record a charge (and no potential voltage difference) similar to that recorded by an electrode in another region of resting myocardium. During depolarization, the outside of the cell becomes electrically neutral with respect to the inside. Therefore, as a wavefront of depolarization travels toward an endocardial electrode that records from resting myocardium, the electrode becomes positively charged relative to the depolarized region. This is manifested in the intracardiac electrogram as a positive deflection. As the wavefront of depolarization passes under the recording electrode, the outside of the cell suddenly becomes negatively charged relative to resting myocardium, and a brisk negative deflection is inscribed in

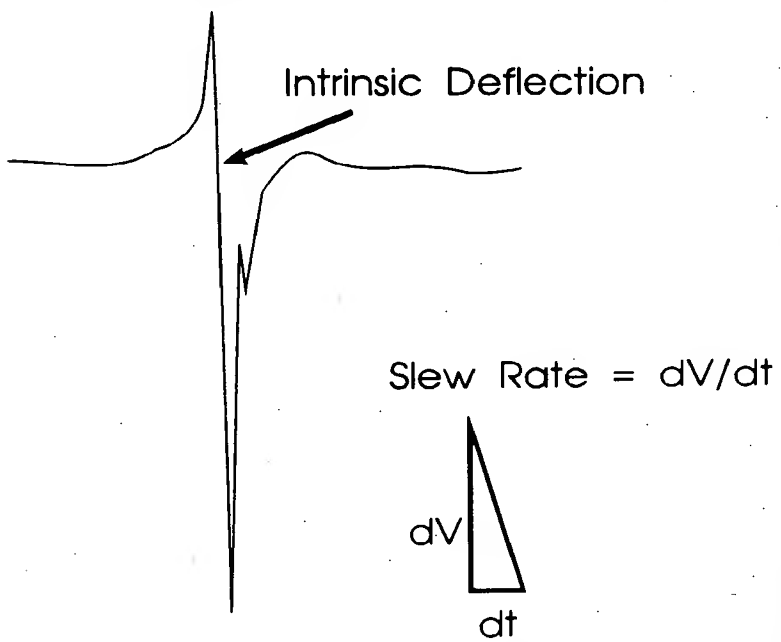

Figure 2.11 **A typical bipolar ventricular electrogram in a normal individual. The sharp downward deflection in the electrogram represents the intrinsic deflection and indicates the moment of activation under the recording electrode. The slope of the intrinsic deflection (*dV/dt*) is expressed in volts per second and is referred to as the slew rate. In order for an electrogram to be sensed by a sensing amplifier, the amplitude and slew rate must exceed the sensing threshold.**

the intracardiac electrogram. The peak negative deflection in the intracardiac electrogram, known as the intrinsic deflection (Figure 2.11), is considered the moment of myocardial activation underlying the recording electrode.[127] The positive and negative deflections that precede and follow the intrinsic deflection represent activation in neighboring regions of myocardium relative to the recording electrode. In clinical practice, the intrinsic deflection in the intracardiac electrogram is usually biphasic, with predominantly negative or positive deflections less frequently observed.[128] Because of the greater mass of myocardium, the normal ventricular electrogram is usually of far greater amplitude than the normal atrial electrogram.

Characteristics of intracardiac

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similar to that of atrial electı
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quencies below 10 Hz mark

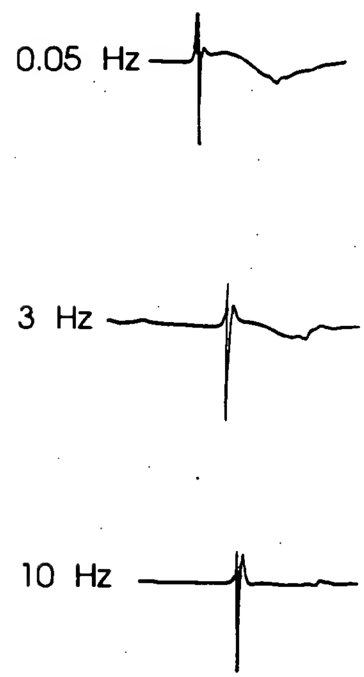

Figure 2.12 **The effects of**
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the far-field R-wav and T-v
than 30 Hz results in marked
tude. The center fr quency
mately 30 Hz, consistent w
intracardiac electr grams.

Characteristics of intracardiac electrograms: The frequency content of ventricular electrograms has been demonstrated to be similar to that of atrial electrograms.[129] By using Fourier transformation, one can express the frequency spectrum of an electrical signal as a series of sine waves of varying frequency and amplitude. Fourier transformation of ventricular electrograms demonstrates that the maximum density of frequencies for R-waves is usually found between 10 and 30 Hz.[129] The effects of filtering the ventricular electrogram are shown in Figure 2.12. As can be appreciated from the figure, removing frequencies below 10 Hz markedly attenuates the T-wave ampli-

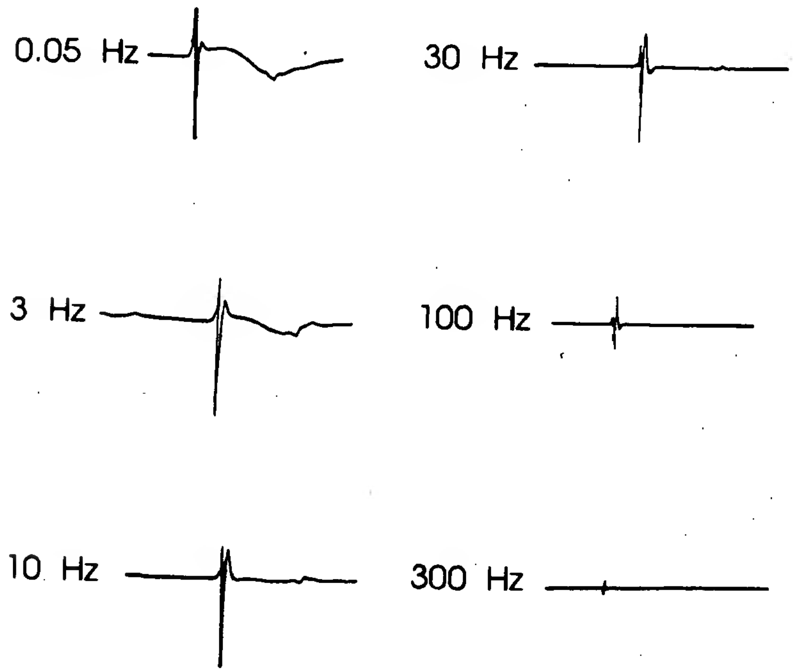

Figure 2.12 The effects of filtering on the bipolar atrial electrogram are demonstrated in an individual. Note that low-pass filtering of the electrogram below 10 Hz has the effect of attenuating the far-field R-wave and T-wave. Filtering of frequencies greater than 30 Hz results in marked attenuation of the electrogram amplitude. The center frequency of most sensing amplifiers is approximately 30 Hz, consistent with the typical frequency spectra of intracardiac electrograms.

tude without significantly influencing the R-wave. The T-wave is usually a slower, broader signal that is composed of lower frequencies, generally less than 5 Hz.[129] Similarly, the far-field R-wave in the atrial electrogram is composed predominantly of low-frequency signals.[130] Therefore, by high-pass filtering of the intracardiac electrogram, many of the unwanted low-frequency components can be removed. In contrast, the frequency spectrum of skeletal myopotentials ranges from approximately 10 to 200 Hz, with considerable overlap with the intrinsic R-wave and P-wave.[129] Although the high-frequency components can be removed with filtering, inappropriate sensing of myopotentials remains a potential problem with the unipolar configuration.[131,132]

In order for the intracardiac electrogram to be sensed by the sense amplifier of an implantable pulse generator, the signal must be of sufficient amplitude, measured in peak-to-peak voltage. In addition, the intrinsic deflection of the electrogram must have sufficient slope. The peak slope (dV/dt) of the electrogram (also known as the slew rate) is of critical importance to proper sensing (Figure 2.11). The sense amplifier of most pulse generators has a center frequency (the frequency for which the amplifier is most sensitive) in the range of 30 to 40 Hz, so that frequencies greater than this are attenuated and less likely to be sensed. Components of the electrogram less than the center frequency are also attenuated, with the output of the filter proportional to the slew rate of the waveform. In general, the higher the slew rate of an electrogram, the higher the frequency content. Thus slow and broad signals with a low slew rate may not be sensed, even if the peak-to-peak amplitude of the electrogram is large. In clinical practice, the slew rate and amplitude of intracardiac electrograms are only modestly proportional.[133] Because of this, both the slew rate and the amplitude of the intracardiac electrogram should be routinely measured.

Unipolar and bipolar sensing

Although both unipolar and bipolar sensing configurations detect the difference in electrical potential between two electrodes, the interelectrode distance has a considerable influence on the nature of the electrogram.[134] If a transvenous bipolar lead is employed for sensing, both electrodes are located in the heart with an interelectrode distance that is usually less than 2 to 3 cm. A unipolar lead utilizes one electrode in contact with the heart and

the other in contact with the pc
with an interelectrode distanc
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unipolar sensing. Bipolar ele

the other in contact with the pocket of the pulse generator, often with an interelectrode distance of 30 to 50 cm. Because both electrodes may contribute to the electrical signal that is sensed, the bipolar electrode configuration is minimally influenced by electrical signals that originate outside the heart. In contrast, the unipolar electrode configuration may detect electrical signals that originate near the pulse generator pocket as well as those from inside the heart. These features of unipolar sensing make this electrode configuration much more susceptible to interference by electrical signals originating in skeletal muscle (myopotentials). The myopotentials associated with pectoral muscle contraction may be sensed by unipolar pacemakers, resulting in inappropriate inhibition or triggering of pacing output.[131,132] Bipolar sensing is relatively immune to myopotentials—a significant clinical advantage. Bipolar sensing is also less likely to be influenced by electromagnetic radiation from the environment than is unipolar sensing.[135] Electrical interference from microwaves, electrocautery, metal detectors, diathermy, or radar is more commonly observed with unipolar than with bipolar sensing.[136–138]

A bipolar electrogram is actually the instantaneous difference in electrical voltage between the two electrodes. Thus a bipolar electrogram can be constructed by subtracting the absolute unipolar voltage recorded at the cathode (versus ground) from the unipolar voltage recorded at the anode (versus ground). Because the bipolar configuration represents the signal at the cathode minus the signal at the anode, the net electrogram may be considerably different than that of either unipolar electrogram alone. For example, if an advancing wavefront of depolarization is perpendicular to the interelectrode axis of a bipolar lead, each electrode will be activated at exactly the same time. Because the unipolar electrogram at each electrode will be similar and inscribed at the same time, the instantaneous difference in voltage will be minimal. In this situation, the bipolar electrogram will be markedly attenuated. A wavefront of depolarization traveling parallel to the interelectrode axis of a bipolar lead will activate one electrode before the other. The resulting bipolar electrogram may have significantly greater amplitude than either unipolar electrogram alone. From these examples it should be recognized that bipolar sensing is more sensitive to the direction that the depolarizing wavefront travels than is unipolar sensing. Bipolar electrograms are more likely to be

influenced by phasic changes in orientation of the lead with respiration than are unipolar electrograms. Because of these considerations, the electrogram measured at the time of lead implantation should be recorded in the configuration that will be used for sensing by the pulse generator.

Another significant difference between unipolar and bipolar sensing relates to the amplitude of far-field signals.[139] Because of the significantly greater mass of the ventricles, the atrial electrogram often records a far-field R-wave (Figure 2.13). For unipolar atrial leads, the far-field R-wave may be of equal or greater amplitude than the atrial deflection. In contrast, the bipolar atrial electrogram usually records an atrial deflection that is considerably larger than the far-field R-wave. The programma-

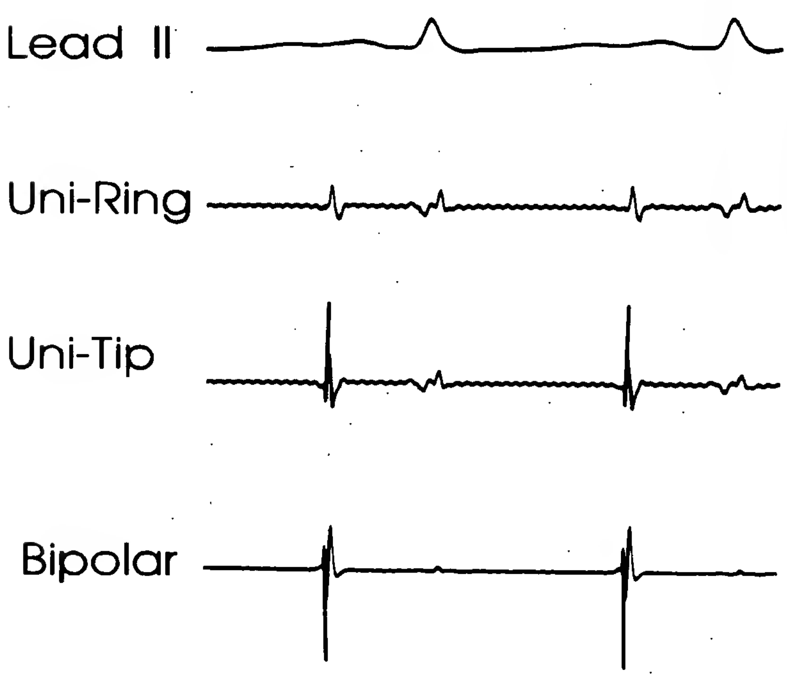

Figure 2.13 Simultaneously recorded unipolar and bipolar atrial electrograms from the ring and tip electr des of a permanent pacing lead. Note that both of the unipolar electrograms record a far-field R-wave. The bipolar electrogram records a sharp atrial deflection and markedly attenuates the far-field R-wave. Bipolar sensing is characterized by a relative immunity to far-field electrical events.

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ble atrial ventricular refractory period of dual-chamber pacemakers has effectively reduced inappropriate sensing of far-field R-waves in the unipolar atrial electrogram. Despite this, far-field R-wave sensing remains an important concern with AAI pacemakers and requires the use of long refractory periods in occasional patients. Atrial antitachycardia pacemakers (AAI-T) that are designed to interrupt atrial tachycardias require the use of short atrial refractory periods in order to detect very rapid atrial rates. Because of concerns regarding the inappropriate sensing of far-field R-waves and myopotentials with unipolar sensing, antitachycardia pacing systems require the use of bipolar leads.

The problem of far-field R-wave detection in the atrial electrogram has been addressed by Goldreyer and colleagues by the development of leads incorporating a pair of closely spaced electrodes placed circumferentially around the catheter.[140–142] This concept, known as an orthogonal electrode array, uses electrodes that are separated by 180 degrees and float free within the atrial blood pool. The advantage of orthogonal sensing is that both electrodes record ventricular activation nearly simultaneously, with a marked attenuation of the far-field R-wave and a greater signal-to-noise ratio. The improved signal-to-noise characteristics of orthogonal electrodes have allowed the use of more sensitive atrial amplifiers and increased reliability of atrial sensing. Orthogonal electrodes have also provided a method for dual-chamber (VDD) pacing that utilizes a single lead.[143] The single-lead concept utilizes an electrode at the tip of the catheter, which is placed at the right ventricular apex for ventricular pacing and sensing, and a pair of orthogonally arranged electrodes located more proximally along the catheter in the atrium for atrial sensing.

Polarization

Following application of a polarizing pulse, an afterpotential of opposite charge is induced in the myocardium at the interface of the stimulating electrode (Figure 2.14). Immediately after cathodal stimulation, an excess of positive charges surrounds the electrode, which then exponentially decays to electrical neutrality. This positively charged afterpotential can be inappropriately sensed by the sensing circuit of the pulse generator with resulting inhibition of the next pacing pulse.[144] The amplitude of afterdepolarizations is directly related to the amplitude and

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has returned to a stable level prior to another QRS complex. During that period the myocardium is more sensitive to cathodal than anodal stimuli and, for a constant current stimulus, equally sensitive to cathodal and bipolar stimuli. Cardiac sensitivity to stimulation changes significantly during and immediately after the QRS complex during the relative refractory period. The phenomenon of pacemaker-induced ventricular fibrillation, in which the stimulus falls into the vulnerable period of the cardiac cycle, has been observed during bipolar stimulation in all published instances except one and is related to the anode of a bipolar electrode (Fig. 4–5). The threshold for pacemaker stimulus induced ventricular fibrillation decreases during myocardial ischemia, infarction, metabolic imbalance, and drug intoxication.

Electrode Metal

The metal for a pacemaker electrode must be:

1. Electrochemically inert.
2. Nontoxic.
3. Resistant to electrolytic destruction.
4. Of low electrical resistance.

The electrode should not go into solution during passage of an electrical current, at least at the conventional pacing pulse duration and output levels. Any salt formed during pacing should be nontoxic. If a metal meets these criteria only as a cathode, then it may be used only for unipolar pacing. Three metals have been successfully used for permanent pacing:

1. Platinum with 10% iridium.
2. Elgiloy, an alloy of cobalt, iron, chromium molybdenum, nickel, and manganese.
3. A silver and stainless steel combination.

The threshold is a function of the reactivity of the metal and the overvoltage developed during passage of a current for cardiac stimulation. The more noble a metal, the lower this overvoltage and consequently the lower the voltage and current pacing threshold. Platinum-iridium has consistently lower thresholds than the more reactive metal, Elgiloy. Nevertheless, all three metals have been quite successful for long-term pacing, and the difference in threshold is inconsequential as a practical matter.

Drug Administration and Electrolyte Balance

Changes in electrolyte concentration have an effect on stimulating threshold. Potassium administration reduces threshold briefly, whereas potassium and insulin in combination increase threshold. Hypertonic sodium chloride increases threshold. Increasing P_{O_2} has little effect; slight hypoxia increases threshold and marked hypoxia reduces threshold. Increase of P_{CO_2} increases threshold and a decrease has little effect.

Glucocorticoids and epinephrine and ephedrine decrease threshold. Isoproterenol, aldactone, propranolol, verapamil, quinidine, and ajmaline all increase threshold. Digitalis, morphine, lidocaine, and procainamide have little effect. All of these agents, at the usual therapeutic levels, have little sustained effect on threshold and can usually be disregarded. Even where a pronounced immediate effect occurs, sustained administration is usually accompanied by a gradual return to baseline cardiac sensitivity.

Unipolar and Bipolar Pacing

Unipolar or bipolar cardiac stimulation refers to the number of electrodes attached to the portion of the heart to be stimulated. Atrial bipolar or unipolar and ventricular bipolar or unipolar stimulation exist. The presence of two electrodes, one in the at-

rium and the other in the ventricle with a common ground electrode, remote from the heart, is not bipolar pacing or sensing but rather unipolar. Whether the pacemaker is called unipolar or bipolar depends on the location of *both* electrodes. More important, all stimulation is really bipolar, as current flows from the negative terminal which must be attached to the heart and returns to the generator via the positive terminal which may be the ring of the bipolar endocardial electrode, a second intramyocardial elecrode identical to the negative lead (as in a thoracotomy implant) or a portion of the pacemaker case.

The stimulus that drives the heart via the cathode will reach the pulse generator anode equally whether the anode is within the myocardium, the ventricle, or elsewhere in the body. The *current* threshold of cardiac stimulation is, therefore, a function of the stimulation aspects of the cathode, and it is equal for unipolar and bipolar configuration. The *voltage* threshold varies as a function of the resistance of the lead system. For example, the ring of a bipolar electrode is a much smaller and, therefore, a higher resistance contact than the case of a pulse generator. The large surface area of the anode of the unipolar generator provides a lower resistance pathway and a lower voltage threshold. The difference is not great. Although more bipolar than unipolar electrodes have been implanted, by far more manufacturers have provided unipolar pacemakers, and these now dominate the field (Table 4–2).

TABLE 4–2

Unipolar/Bipolar Pacing (Permanent Leads)

	UNIPOLAR	BIPOLAR
1. Implantation		
Transthoracic	Easier	
Transvenous	Easier	
2. Threshold		
Current	Equal	Equal
Voltage	Lower	
3. Durability	Equal	Equal
4. Sturdiness	Equal	Equal
5. QRS sensing	Greater	
6. VF liability		Greater
7. Follow-up	Easier	
8. ECG analysis	Easier	
9. EMI		Resistant
10. Repair	Easier	

UNIPOLAR AND BIPOLAR SENSING

The unipolar electrogram is the result of the passage of the depolarization wave

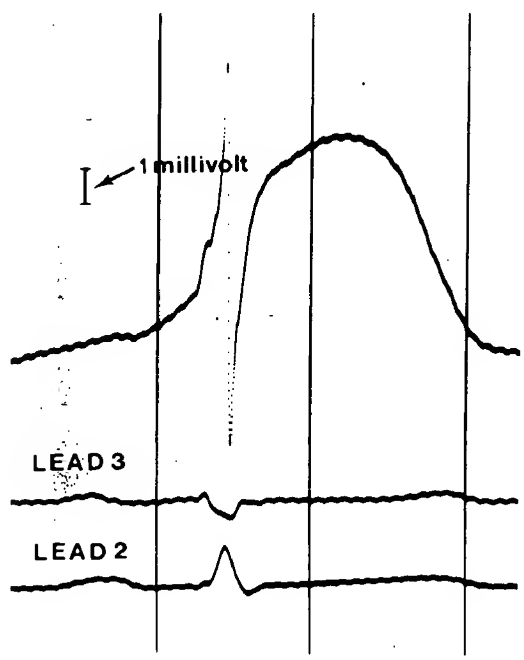

Fig. 4–6. Typical unipolar ventricular electrogram timed for its events against lead 2 and 3. The pacemaker is triggered by intrinsic deflection, the vertical rapid indicator of the passage of current past the electrode. The elevated S-T segment is the "current of injury." When the electrode becomes chronic, the S-T segment becomes isoelectric. Intrinsic deflection changes little in amplitude but decreases by about 40% in rate of development (dv/dt).

front past the intracardiac electrode (Fig. 4–6). The subcutaneous, remote electrode is too far removed for any signal it detects to play any significant role in the net bipolar signal. Over 2000 electrograms recorded during pacemaker implant and pulse generator replacement were analyzed for the following:

1. Configuration, i.e., morphology of the depolarization wave, the QRS complex.
2. The amplitude of the complex.
3. The rate of development (slew rate) or change in voltage as a function of time (dv/dt) of the "intrinsic deflection," (ID), and the vertical straight line portion of the intracardiac signal which triggers the pacemaker.
4. The presence of injury and repolarization waves, the analogs on the peripheral ECG or the ST segments and T waves.

Additional signals occasionally appearing are far field and represent electrical activity distant from the electrode, i.e., skeletal muscle potentials, the contraction of the other ventricle, external electromagnetic interference, and occasionally stimuli from another electrode, as in AV sequential pacing system (Fig. 4–7).

The bipolar signal results from the subtraction of the signals from both cardiac

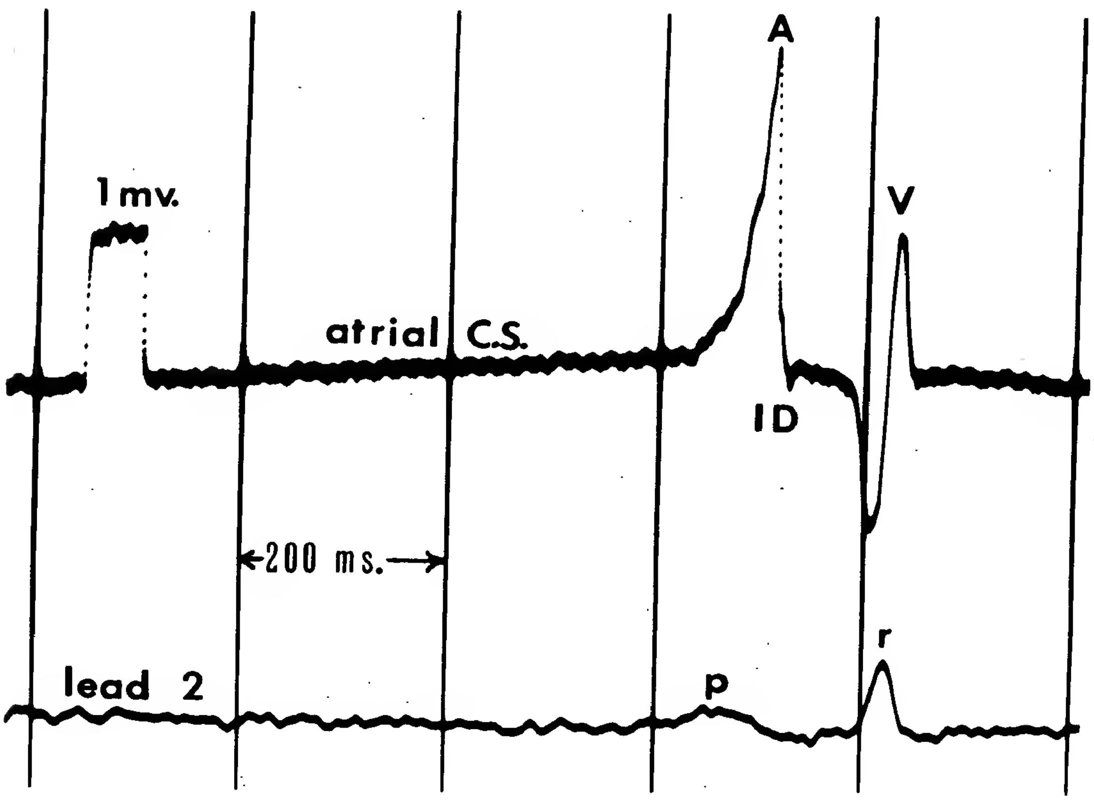

Fig. 4–7. Far-field signal may be the QRS complex when sensing the P wave from the atrial appendage or coronary sinus. Bipolar electrodes sense far-field signals far less than unipolar.

poles. Each individually presents a unipolar configuration; the interaction of the two produces the bipolar signal. If the bipolar axis is at right angles to the depolarization pathway the two signals are identical and simultaneous at each pole. These will cancel, producing a small or zero bipolar result. In this circumstance conversion from bipolar to unipolar increases the net signal. A parallel electrode orientation causes delay of the same signal at one pole relative to the other and can result in an augmented bipolar signal greater than either unipolar component. The delay also produces a signal with two intrinsic deflections compared to the single intrinsic deflection of the unipolar electrogram. During transvenous pacing the net bipolar signal also depends on the signal on the proximal electrode. If that electrode contacts contractile tissue, the ID will be large; if it is separated from viable tissue, the ID will be of small amplitude and the rate of rise slow. In that instance the signal will be poor, and the net bipolar signal will be a reflection of the signal from the electrode tip.

Comparison of a group of ventricular electrode bipolar and tip signals, simultaneously recorded, shows that bipolar sensing has the following characteristics:

1. Intrinsic deflections are increased or decreased, more widely variable compared to unipolar signals, but without a significant difference of the mean of bipolar and unipolar electrograms, i.e., the scatter of bipolar is greater, largely because of a second signal, which does not appear in unipolar electrograms.
2. The duration of the intrinsic deflection is significantly shortened, by a mean of 28%.
3. The injury currents are attenuated by 37%.
4. The T waves are attenuated by 34%.
5. The far-field effects are substantially reduced.

The first of these five qualities is equal for both unipolar and bipolar electrodes; for the last four the advantage is with the bipolar configuration.

The sole disadvantage of the bipolar configuration is the wider scatter of signals and the possibility of ID attenuation if the electrodes are oriented at exactly a right angle to the wave propagation. Overall, 2% of bipolar signals are too small to be sensed (when the unipolar analogous signal would be adequate) and they are smaller than the unipolar tip signal in a total of 51%. In 43% the bipolar ID is larger than the unipolar and in 6% the two are equal. Bipolar S-T

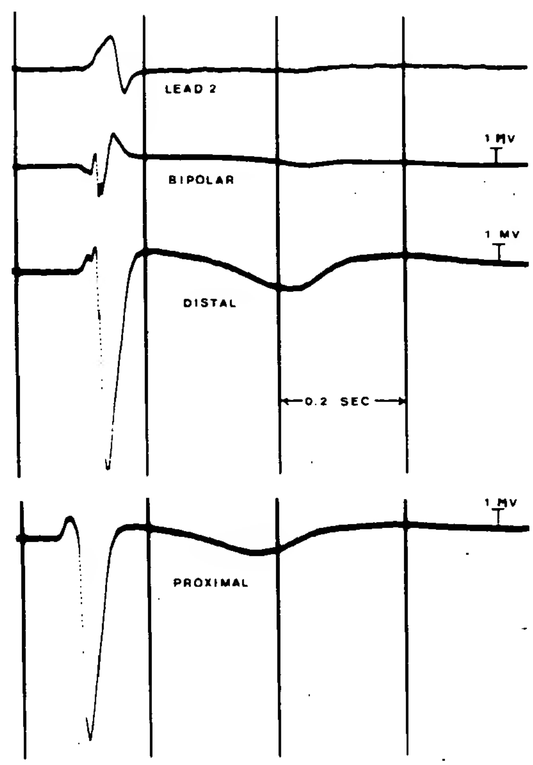

Fig. 4–8. Bipolar electrogram from transvenous electrode timed against lead 2. In this instance, large proximal and distal (or tip) electrograms are of almost equal amplitude and oriented so that two signals subtract and produce a bipolar signal smaller than either.

segment elevation and distant potentials are smaller than those for the unipolar electrode in 96%.

The bipolar electrode cancels far-field, electromagnetic, and injury signals, as these "noises" arrive simultaneously and at equal amplitude at both poles. The ID otherwise almost always affects the poles unequally and/or nonsimultaneously and is augmented rather than diminished. The effect is improvement in signal-to-noise ratio, caused only by the geometry of the sensing electrode, independent of circuit factors (Fig. 4–8).

Conventional wisdom has held that bipolar sensing has been inferior to unipolar sensing because of the much longer unipolar dipole from the intracardiac cathode to the subcutaneous anode. Conversion of a bipolar to a unipolar system has been recommended to improve poor sensing. Evaluation of a series of simultaneously recorded unipolar and bipolar signals from the same bipolar electrode, with the unipolar signal referenced to the usual position of the subcutaneous anode, has shown that the belief of bipolar sensing inferiority is not well founded.

Though unipolar pacemakers have been more widely implanted and in greater numbers than bipolar, the possibility of greater dispersion of electromagnetic interference in the world may increase the relative safety of bipolar compared to unipolar electrodes. In that circumstance be aware that bipolar and unipolar pacing are virtually equivalent.

The factors outlined in this chapter are of prime importance to the comprehension of the remainder of this book. Knowledge of the physiology and technology of cardiac pacing is critical. The practitioner overlooks basic principles at his peril and that of his patient. The question of which electrode to use, large or small, unipolar or bipolar, and whether by thoracotomy or transvenously, arises daily. The utility of programmability of output to ascertain postimplant threshold, increase output to accommodate a high threshold or decrease output to prolong longevity is of great value. The cardiac electrograms describe generator sensing requirements, circumstances in which sensing may be satisfactory or poor, and the possible methods of management.

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